FIRE ENGINEERING

THERMAL PERFORMANCE AND LIMITATIONS OF BUNKER GEAR

BY J. RANDALL LAWSON

Structural firefighters' protective clothing is designed to protect its wearers from the thermal environments experienced during firefighting. This includes protection from thermal radiation, hot gas convection, and heat conducted from hot surfaces.[1] Protective clothing may respond differently to each of these three modes of heat transfer (radiation, convection, and conduction). Firefighters may receive serious burn injuries from each of these modes of heat transfer or a combination of them even though they are wearing protective clothing and may be a significant distance from a fire. The reason for this is that protective clothing has definite physical limits to its ability to protect the wearer. All thermal protective clothing has these limits, which are measurable. A working firefighter may not recognize these critical limits until he is already experiencing a burn injury.

BURN INJURIES

It has been said that a burn injury is the most painful injury that the human body can experience. The average hospital stay for a victim with a severe burn injury is more than three times that for typical medical and surgical patients.[2] Burn injuries often cause physical scars that last a lifetime. These scars are usually accompanied by serious psychological scars that affect not only the burn victim but also family and friends. In addition, fire service administrators know that the monetary cost for burn injuries can be high, and the burn victims know that their injuries may have a significant impact on their ability to earn a living. The threat of injury and loss of financial security is a real part of a firefighter's everyday life. Firefighters know that the job is risky, and they also know that they are much better prepared to manage these risks. Firefighter training provides the knowledge to manage the risks, and the advanced protective clothing and equipment give firefighters some important tools for managing the risk. However, there appears to be some gaps in training and safety management that contribute to thousands of burn injuries experienced annually.

While working with numerous fire departments over the past five years, I have learned that very little time is given to teaching firefighters about the causes of burn injuries and the limits of their thermal protective clothing.

The new outer-shell materials, moisture barriers, and thermal barrier materials have performance characteristics that easily exceed those of the garments used by firefighters from the past generation. Many of these new materials are spin-offs from the space program. Firefighters' protective clothing and space suits used by America's astronauts share common materials and technologies. However, when comparing training for the two risky occupations, it is clear that astronauts develop a much better understanding of their protective clothing limits than the average firefighter. The thermal environments experienced while fighting fires may easily be greater than those faced by an astronaut working outside of a spacecraft. Both environments may cause serious injury or death in a matter of seconds. The dangers experienced in fire-generated thermal environments can be much greater for firefighters than for astronauts. As an example, NASA designs space suits for our area of the solar system for temperatures that vary from about −156°C (−250°F) to

■ **J. RANDALL LAWSON** is a physical scientist at the National Institute of Standards and Technology, Building and Fire Research Laboratory. He has studied fire and fire safety for more than 25 years with industry and the NIST. He was the leader of an industrial fire brigade and is currently the project leader for the Fire Safety Engineering Division studies on firefighter protective clothing. He is a member of the following NFPA Technical Committees: Structural Fire Fighter Protective Clothing and Equipment, Special Operations Protective Clothing, and Equipment and Fire Tests. He is also a member of the following American Society for Testing and Materials (ASTM) Committees: F-23 on Protective Clothing and E-5 on Fire Tests. He may be reached by e-mail: jlawson@nist.gov.

121°C (250°F), a temperature range of 277°C (500°F).[3] Firefighters in their work may experience thermal environments ranging from about −34°C (−30°F) in northern climates to about 1,000°C (1,832°F) in a postflashover fire, a temperature range of 1,034°C (1,862°F). This is a significant difference in thermal environments. It points out the fact that firefighter basic training must prepare firefighters to properly use their protective clothing and properly manage their thermal exposures through the use of effective tactics. Failure to properly use protective clothing or to effectively use sound firefighting tactics will often lead to serious burn injuries.

THERMAL BURNS

A thermal burn may be defined as the destruction of human tissue by the application of heat. People may also receive burns from chemicals and nuclear radiation, but these injuries are not addressed in this article. From basic first aid, most people know that burns are classified according to *extent* (or area) and *depth* (or degree) of tissue injury.[4,5] The degrees of burn injury most easily recognized are defined as follows:

- First-degree burns cause the surface layer of the skin to become reddened, and it typically becomes welted or slightly swollen.
- Second-degree burns affect the surface skin and deeper layers of tissue and are characterized by blister formation.
- Third-degree burns destroy the surface layers of skin and damage deeper tissues. Third-degree burn tissue may exhibit broken blisters and charring. Second- and third-degree burns are considered serious injuries because they often involve relatively large areas and represent wounds that have a potential for producing further injury.

Burn injuries are considered to be particularly serious if they cover 10 percent or more of the body and if they involve the area about the mouth and face, where they may interfere with respiration. (4)

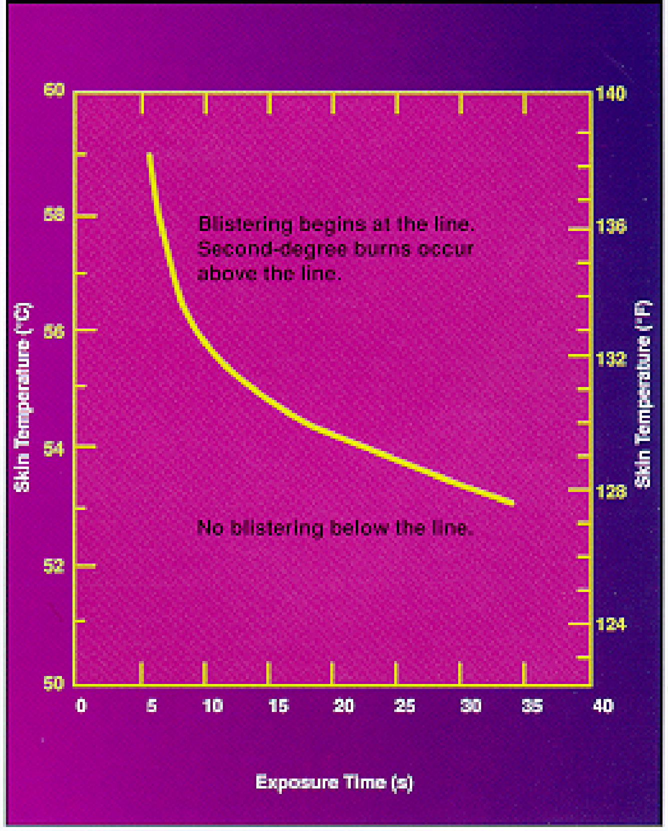
Basic treatment for burn injuries is designed to prevent additional injury, relieve pain, prevent shock, prevent infection, and keep the surface from forming hard constricting scars that will do further damage. (5)

Now that burn injuries have been defined, it is appropriate to ask the question: At what skin temperature does one receive these various burn injuries? Table 1, top right, provides skin temperature estimates relative to the onset of the various degrees of burn injury.

TABLE 1. BURN INJURY AND ESTIMATES OF SKIN TEMPERATURE[5]

Type of Injury	Temperature °C (°F)
Experience discomfort or pain	44°C (111°F)
First-degree burn	48°C (118°F)
Second-degree burn	55°C (131°F)
Third-degree burn	>55°C (>131°F)
Instantaneous skin destruction	72°C (162°F)

Figure 1. Exposure Threshold Conditions for Skin Blistering



As can be seen from the table, burn injuries occur at relatively low skin temperatures. A person experiences discomfort or pain with a skin temperature of about 7°C (12°F) above normal body core temperature, 37°C (98.6°F). A second-degree burn occurs with a skin temperature of only about 18°C (32°F) above normal body core temperature, and instantaneous skin destruction is only 35°C (63°F) above normal core temperature. This information illustrates that burn injuries occur when the skin temperature is elevated only a few degrees above normal. This does not mean that a burn immediately occurs when the skin comes in contact with a gas, liquid, or hot surface that is at 48°C to 55°C (118°F to 131°F). It usually takes a little time for the skin to heat to a critical temperature that results in a burn.

Prolonged exposure to this thermal environment or higher temperatures will ultimately cause the skin temperature to rise to a critical point where heat losses that protect the skin can no longer be maintained, and a burn occurs. Heat losses from the skin are controlled by blood flow to and from the exposed area, thermal radiation from the skin's surface, and sweating. Exposure to 55°C (131°F) tap water can be very uncomfortable, and yet no burn occurs if the hand is quickly removed from the water. Leaving the hand in the hot water over a period of time will cause a burn, and the higher the temperature, the quicker the burn injury will occur. This is shown by the plot of time and temperature data for skin blistering published in the "Project Fires" study.[6] See Figure 1 above. The line on this plot represents a series of critical time and temperature points where second-degree burn blistering occurs. The area above the line represents the potential for increasing injury with time. This graph shows that relatively small changes in time and skin temperature can lead to serious burn injuries. Once a firefighter's protective clothing has been heated and the skin temperature has risen to the dangerous levels mentioned above, it is unlikely that a firefighter can immediately remove the protective clothing to start the cooling process and prevent additional injury.

NFPA 1971

Firefighters' protective clothing and equipment manufactured to current National Fire Protection Association (NFPA) standards give

(Top left) Firefighter protective clothing used in a field study with Fort Indiantown Gap (PA) Fire Department. (Photo by Jay McElroy, NIST.) (Top right) This study focused on the possible relationship between firefighters' protective clothing and the burn injuries of a fire fatality. (Photo by author.) (Bottom right) The association between firefighters' protective clothing and burn injuries from a nonfatal fire exposure was explored in this study. (Photo by author.)

fire service personnel a significant degree of protection when compared with items used 20 years ago. These new garment designs take into account the dynamics of body movement and other relevant human factors.

Firefighters' protective clothing that meets the requirements of NFPA 1971, *Protective Ensemble for Structural Fire*—1997, is tested for thermal performance using two bench scale fire test methods. These tests measure resistance to fabric flaming and heat transfer through the protective clothing system when exposed to a limited heat source.

The Flame Resistance test uses a specimen measuring 7.6 cm × 30.5 cm (3 in. × 12 in.) and exposes it to a small gas flame (1). This test measures the time that a fabric flames after the gas flame is removed from the specimen and the length of charred fabric at the end of the test. This test method has proved to be useful in helping to develop the flame-resistant fabrics currently being used in firefighters' protective clothing.

The Thermal Protective Performance test (TPP) is used to measure heat transfer through a specimen of protective clothing. This test specimen is generally constructed from outer shell, moisture barrier, and thermal liner materials. (1) The specimen area exposed to the thermal environment measures about 101 mm by 101 mm (4 in. by 4 in.). This small test specimen is exposed to a brief thermal environment produced by quartz radiant tubes and flames from two laboratory burners. The thermal exposure, 80kW/m² (2 cal/cm² sec) is designed to represent a moderate level flash fire condition. This test procedure provides a means for measuring heat transfer through a protective clothing system and for predicting the potential for burn injury from this limited heat and flame exposure.

These two test methods address only cases where the firefighter comes in direct contact with a flame or is enveloped in flames. These two test methods have done much to improve the performance of firefighters' protective clothing. However, these tests don't provide the information the firefighter, protective clothing designer, and laboratory technician need to understand the thermal limits of protective clothing. These undefined limits are critical to understanding how burn injuries are occurring. These test methods don't allow for the evaluation of protective clothing in thermal environments that are less or greater than the test conditions specified.

NIST DATA[7]

Data developed by the National Institute of Standards and Technology (NIST) indicate that firefighters may receive serious burn injuries from thermal exposures that are much less than those experienced in the Flame Resistance or the TPP test.[8] In addition, research has shown that firefighters may experience fire environments much more severe than the 80kW/m² (2 cal/cm² sec) exposure from the TPP test. The NIST has been working with the U.S. Fire Administration, members of the fire service, and manufacturers of protective clothing materials to better understand these firefighting environments. These efforts are focused on understanding the critical limits of firefighters' protective clothing when exposed to these various firefighting environments. Some findings from this work have been published by the NIST in NISTIR 5804, *Fire Fighter's Protective Clothing and Thermal Environments of Structural Fire Fighting*. (8) This article summarizes findings from this NIST publication, attempts to clarify the concepts of heat transfer in protective clothing, and addresses the relationship of these concepts to firefighter burn injuries. These studies are based on what is currently known about structural fires in North America, and it is apparent that structural fires, particularly in homes, grow more quickly and release significantly more energy than they did 50 years ago.

FIRE INTENSITY

Today, fire loads (mass or weight of fuel per square area, kg/m² or lbs/ft²) in our homes are estimated to be about two times greater than they were in the 1940s. (8) This is based on two fire loads surveys, one conducted in 1942 and the second in 1980. (8) Fire loads for current day homes ranged from 29.3 kg/m² to 125.5 kg/m² (6.0 lbs/ft² to 25.7 lbs/ft²). Also, fire tests of furniture show that modern chairs when burned may release 10 times the heat energy as chairs commonly used during the first half of this century. (8) The soft comfortable chairs we all tend to enjoy typically produce higher energy release rates. These fires, when combined with modern building materials and construction methods, provide a significant challenge for firefighters and their protective clothing. This is demonstrated by data published by the NFPA on firefighter burn injuries. These data for the past 10 years show that there has been no significant decline in the number of firefighter burn injuries even though there has been noticeable improvement in protective clothing.[9] Part of this may be explained by the concept that fast growing, intense fires require more aggressive tactics. This concept in itself may cancel any improvements made in protective clothing during the past decade. Another factor that puts a firefighter closer to a structural fire than was typical several decades ago is the use of self-contained breathing apparatus (SCBA). The practice before SCBAs became common in the fire service was that the firefighter didn't typically go where there wasn't relatively safe air to breathe. Today, firefighters with their advanced protective clothing and SCBA can enter lethal concentrations of gases with little effort. As these dangerous areas are entered, the firefighter comes much closer to the fire and is able to stay longer in these hostile thermal environments. These advances in firefighting ability appear to have closed the gap that was being formed by the advances in protective clothing. The firefighter is again being exposed to thermal environments that test the limits of protective clothing.

PROTECTIVE CLOTHING AND BURN INJURIES

The thermal protective clothing used by the fire service today is the best that has ever been made. In the past 20 years, materials manufacturers have developed new fabrics that resist destruction from heat and flame. These fabrics don't show thermal damage until they are exposed to temperatures well above that needed to decompose untreated cotton, 250°C (482°F).[10] The fact that these fabrics don't show visible damage at high relative temperatures is a good economic factor for the fire service. However, this lack of visible damage to the protective clothing of a seriously burned firefighter sometimes creates difficulties when attempting to identify causes for the injury. While the new fabrics and materials were being developed, protective clothing manufacturers were developing new clothing designs to meet fire service requests. These design changes have increased thermal protection through the use of modern thermal barrier materials. New moisture barrier materials were added, and the industry has designed clothing systems intended to provide comfort and ease of movement. As a result, structural firefighters' protective clothing ensembles have become complex engineered garment systems. These advancements in protective clothing materials and design have created some unexpected effects for the firefighter.

Heat stress has become a significant factor for the fire service. It has been identified as one of the primary challenges for fireground safety.[11] The occurrence of burn injuries where protective clothing exhibits no visible thermal damage is sometimes difficult to explain. It is vital that firefighters understand the causes for all burn injuries they may receive. They must be able to apply this knowledge when assessing personal safety at the fire scene. Knowledge related to the causes of burn injuries enables the firefighter to select safe and effective firefighting tactics.

HOW BURN INJURIES OCCUR

How do firefighters get seriously burned even though there is no apparent damage to their protective clothing? These burn injuries may happen in several ways, but certain heat transfer factors can help us to understand the reasons for the injuries.

- Did the firefighter's protective clothing provide enough delay time in heat transfer to allow the individual to enter a thermal zone hot enough to cause a burn injury?
- Did the firefighter come in direct contact with a flame? In cases of injuries in which the protective clothing shows no damage, firefighters are often never touched by a flame. These burns are generally caused by thermal radiation from the fire or direct contact with a hot surface.
- Did the firefighter's protective clothing become compressed against a hot surface?
- Was the firefighter's protective clothing wet or dry?

In many cases, burn injuries that have occurred with no protective clothing damage are reported to be steam burns or scalds, but further analysis of the way that heat is transferred through the protective clothing shows that these injuries generally occur well before steam is generated. Webster defines a scald in the following way: *"1: to burn with or as if with hot liquid or steam."*[12] In a traditional sense, all of these types of burn injuries may be referred to as scalds if a hot liquid, a hot vapor, or steam is involved. As previously noted, a first-degree burn injury occurs with a skin temperature of about 48°C (118°F), and a second-degree burn occurs with a skin temperature of about 55°C (131°F). Instantaneous skin destruction occurs at a temperature of about 72°C (162°F). These temperatures are much lower than the boiling point of water, when steam is formed. Steam is normally thought of as being formed from water at a temperature of 100°C (212°F). Steam is not the visible white cloud that most people call steam. Steam is a transparent gas that is not generally seen by the human eye. The white cloud that usually accompanies steam is made up of small cool water droplets that have condensed into the air from steam and water vapor. In addition to the dangers produced by steam from boiling water, you must also be concerned with hot water vapor produced by heated water. This hot water vapor can also produce serious burn injuries.

EFFECTS OF MOISTURE

Moisture in firefighters' protective clothing functions in a complex fashion. In certain cases, moisture may help to protect a firefighter. With only slight changes in thermal environment, moisture may cause serious burn injuries. The problem with this variability is that the firefighter generally doesn't recognize the changes in moisture and thermal conditions that convert beneficial moisture into a dangerous element. This recognition of the change in moisture performance usually doesn't occur until a firefighter has already felt pain and suffered skin damage.[13] However, training that provides firefighters with insight into the causes of these types of serious burn injuries may help them to prevent the injuries.

Research by Veghte[14] shows that humans have the ability to produce substantial quantities of moisture as sweat. Sweating rates from humans carrying out heavy exercise activities, as would be expected with firefighters, range from 1,200 g/hr to 1,800 g/hr (2.6 lbs/hr to 4.0 lbs/hr). (14) Once sweating has begun, firefighters become susceptible to moisture-related thermal injuries.[15]

However, as shown earlier, these burn injuries can occur with skin temperatures well below the temperatures that produce steam, and they generally don't involve contact with hot liquids. Moisture produced by sweating and potentially from hose spray may be absorbed by the firefighter's protective clothing. Moisture located on the outside of the protective clothing or on the outer shell can produce rapid cooling through evaporation or runoff that carries heat away from the clothing. Moisture trapped inside the protective garment, absorbed by the protective garment's thermal liner and the firefighter's clothing, would not likely evaporate from the garment system as easily as moisture on the outer surface. Therefore, moisture on the inside of the garment would not be expected to produce the same rate of evaporative cooling. This moisture may actually result in a decrease in the thermal protection provided by the garment, especially during fabric compression. (15)

TYPES OF BURN INJURIES

Wet Compressed Garment Burn

Wet clothing exhibits significantly greater rates of heat transfer than dry clothing. Take as an example a person who is cooking dinner using a cast-iron frying pan. The person uses a dry potholder to move the hot frying pan from one stove burner to another. The potholder was designed and constructed from insulating materials for this thermal protection job, and little or no heat is felt by the person's hand. (The potholder, as well as firefighters' protective clothing, uses materials that insulate by taking advantage of air space within the fabric and fiber system.) The potholder is laid on a wet table, where it absorbs moisture. Subsequently, the person then uses the same potholder, which is now wet, to move the hot frying pan again. This time heat rapidly travels through the pot-holder, causing the person to feel pain and drop the pan. The reason for this change in heat transfer results from moisture having been absorbed by the insulating fabrics and fibers. Moisture in the potholder, plus compression of its insulating air space, allowed heat to travel through at a high rate.

How fast will water transfer heat in comparison with air? Liquid water will transfer heat about 21 times faster than air at a temperature of 93°C (200°F).[16]

For example, if air transfers 10 units of heat, then water at this same temperature will transfer 210 units of heat. This difference results from the material's thermal conductivity. As in the example above, wet compressed thermal protective clothing has a much higher thermal conductivity than dry clothing. To further develop the concept of wet compressed clothing burn injuries, note that protective clothing compression can happen without touching any surface. Arm, leg, and body movements will cause fabric compression in protective garments. Bending the arm generally causes compression of clothing along the forearm, elbow, and biceps. Squatting causes clothing compression across and behind the knee, the thigh, and sometimes the lower leg. Rotating the body in a defensive movement, turning away from a fire, will compress clothing against the upper arm and shoulder and across the upper part of the back. Serious burn injuries of the type discussed above often occur with the compression of wet protective clothing that is exposed to high levels of thermal radiation. Another significant cause of burn injuries to the knees and lower legs results from the compression of wet protective clothing when a firefighter is crawling on a hot floor or roof or through hot water and other liquids.

Drying Garment Burn

Wet protective clothing when worn in typical work or firefighting environments will generally have evaporative heat loss. This heat loss through evaporation is usually beneficial by helping to keep the firefighter cool. However, this cooling effect may allow a firefighter to enter a significantly dangerous thermal zone without realizing it. Evaporative heat loss in firefighters' protective clothing is regulated by the following: the amount of heat energy coming into the garment; the relative humidity of the atmosphere around the firefighter; the protective clothing properties that allow moisture to evaporate; and the rate of moisture replacement, wetting, as evaporation continues. Moisture replacement to the inside of firefighters' protective clothing results from a person's rate of sweating, and moisture replacement on the outside of protective clothing in firefighting environments usually results from hose spray wetting, although some outside wetting may result from rain or snow.

If the evaporation rate increases without moisture being added to restore the thermal balance, the protective clothing dries out, and cooling stops. Evaporation rates increase as a firefighter enters higher temperature and thermal radiation zones near a fire. Firefighters may find that evaporative cooling has provided a false sense of security and that it has allowed them to enter an extremely dangerous thermal environment. This danger is not usually recognized until the last few seconds of protective clothing drying. As drying occurs, the protective clothing temperature may rise very rapidly, producing temperatures inside the garment that will likely cause serious burn injuries. Figure 2 on page 52 provides an example of how thermal protection changes in firefighters' protective clothing as it becomes dry.[17]

This graph shows the temperature rise of a turnout coat shell and the thermal liner surface next to the skin as moisture evaporates. In this example, sweat was simulated by wetting only the thermal liner. Compare the thermal liner temperature with the temperatures that cause burn injury. It is apparent that a person wearing this protective clothing may receive a burn injury within seconds after the clothing begins to dry. In addition, if a firefighter is exposed to higher environmental temperatures or a greater radiant heat flux, drying will be more rapid, and the burn injury will occur faster.

Normally in both of the cases discussed above, there is no thermal damage showing on the firefighter's protective clothing in the area in which the injuries occurred. These injuries typically occur when the firefighter has not come in contact with a flame. They often result from contact with a hot surface or exposure to thermal radiation from the fire.

Steam and scald burn injuries appear to be relatively common. Discussions with firefighters and reviews of firefighter burn injury cases suggest the following.

Steam Burn

Steam burn injuries may occur in structural firefighting when hose streams or sprays are applied to flames or hot surfaces. Steam generated during firefighting expands away from the flames and hot surfaces where it's produced and often comes in direct contact with firefighters. This steam will immediately burn exposed skin, and since it's a gas, it will likely cause burn injuries as it passes through permeable components of firefighters' protective clothing. One of the most important factors related to the severity of steam burns results from the phase change of water gas to liquid water (condensation). This phase change occurs at a constant temperature and allows the great quantity of heat stored in this phase transition to be deposited on the skin.

TABLE 2. HUMAN TISSUE TEMPERATURES COMPARED WITH THERMAL SENSATIONS, APPEARANCE, AND INJURY.[13]

TISSUE TEMPERATURE (°C)	(°F)	SENSATION	SKIN COLOR	PROCESS	INJURY
72	162	Numbness	White	Protein Coagulation	Irreversible
68 62	154 144		Mottled Red and White	Thermal Inactivation of Tissue	Possibly Reversible
60	140	Maximum Pain	Bright Red		Reversible
52	126	Severe Pain			
48	118	Pain	Light Red		
44	111	Pain Threshold			
40	104	Hot	Flushed	Normal Metabolism	None

Scald Burn

Firefighters receive scald burns when they come in contact with a hot liquid (water, liquefied tar, or industrial liquids, for example) that is flowing or splashing from the ceiling and walls of a structure or when a hot liquid is puddled or running on a floor. This hot liquid will burn exposed skin and penetrate certain elements of protective clothing, producing burn injuries. In cases where protective clothing becomes wet when a hot liquid and the garment become compressed, heat will quickly be transmitted to a firefighter's skin, potentially resulting in a burn injury.

In addition to these burn injuries associated with moisture, burn injuries can happen when moisture is not a contributing factor. These injuries can also occur without any apparent damage to a firefighter's protective clothing.

Dry Garment Burn

Thermal degradation (charring) of cotton that has not received fire retardant treatment occurs at a temperature of 250°C (482°F).[10] (10) Fabrics used in firefighters' protective clothing exhibit thermal degradation at temperatures significantly higher than that of cotton. Compare the thermal degradation temperature for untreated cotton with the temperature for instantaneous skin destruction. Instantaneous skin destruction occurs at a temperature of 72°C (162°F) or about 178°C (352°F) below the charring temperature of cotton. Therefore, a firefighter can receive a serious burn injury in dry protective clothing, and there will be no thermal damage showing on the protective clothing.

PAIN AND A BURN INJURY

From the above discussion, it can be seen that burn injuries can occur in several different ways and that these injuries are regulated by heat transfer physics. However, this doesn't answer the fire service's questions related to how you can recognize the appropriate time to begin defensive measures for preventing burn injuries. Discussions with numerous firefighters have focused on the length of time necessary to sustain a burn injury once the pain threshold has been reached. Research has shown that the sensation of pain signals the onset of skin destruction. (13) Normally, tissue damage at this point in time is easily reversed by cooling the affected area. This immediate cooling of the affected area is not the usual case in a firefighting situation.

Figure 2. Temperature Rise in Wet Protective Clothing Resulting from Drying

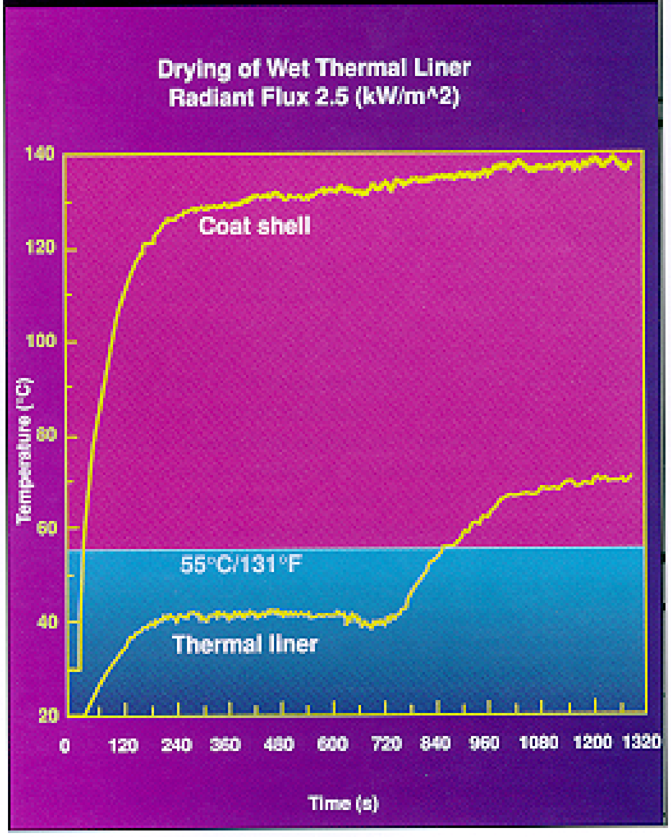


Table 2 on page 52, drawn from ASTM Standard C1055, provides more detailed information concerning skin temperature and its relationship to tissue damage. Note in Table 2 that there is a very small range of skin temperatures related to the sensation of pain and that these temperatures are significantly low when compared with typical firefighting exposures. (18) Once pain is felt, depending on the firefighter's actions and the thermal environment, a serious burn injury may occur within one second. This represents a very short alarm time. The concept of alarm time, the time from feeling pain to the time for sustaining a second-degree burn, has been used for a couple of decades. The term *alarm time* is primarily applicable to laboratory testing where thermal measurements are being made under controlled laboratory conditions. Alarm time as measured in a laboratory would not be expected to relate well to actual firefighting environments, where thermal environments are variable and extremely dynamic. Information gained from discussions with many firefighters who have been burned suggest the following:

- When pain is felt, it may be assumed that a burn injury has already occurred. This burn may be a first-degree burn or greater, depending on the amount of available heat energy, the amount of energy absorbed by the skin, and the exposure time.
- If pain is felt, time becomes a critical factor for reducing the severity of the burn injury.
- When pain is felt, remaining in the firefighting environment will likely increase the severity of the burn injury. The skin's affected surface area will likely increase in size, and the degree of tissue damage is likely to increase.
- If a firefighter is able to exit from the thermal environment that has caused the initial injury, heat contained in the protective clothing (latent heat or stored energy) will likely increase the severity of the injury until the garments can be removed. A burn injury will increase in severity as long as the skin temperature is equal to or greater than 44°C (111°F).[19]
- If hose streams are applied to a firefighter to extinguish flames on the clothing or to cool burn injuries, there is the risk of producing scald burns. The firefighter being wet down must be away from thermal environments that can convert water in the protective clothing to hot vapors or steam. Also, to be effective, relatively large quantities of water may be needed to appropriately cool the protective clothing and human tissue so that hot protective clothing and equipment don't convert the water to dangerous hot vapors.
- Firefighters have indicated that they generally underestimate the severity of their burn injuries while they are working and don't realize the magnitude of the injury until they remove their protective clothing. As Table 2 indicates, human tissue becomes numb on reaching a temperature of 62°C (144°F). (13)
- When pain is felt from a thermal exposure, a firefighter must make a sudden decision to provide for his safety.
- The above discussion suggests that anytime a firefighter feels pain from a thermal exposure, the time for improving tactics to prevent injury has already passed and immediate action is required to reduce the threat of greater injury.

* * *

This article has discussed various conditions under which firefighter burn injuries occur when there is no visible thermal damage to the firefighter's protective clothing. Improved understanding of these phenomena that result in firefighter burn injuries is being made through laboratory and field studies conducted by the NIST.

New methods are being developed for measuring the thermal performance of firefighters' protective clothing systems while being exposed to varying firefighting thermal environments. These methods will allow researchers to make detailed measurements of heat flow through thermal protective clothing specimens when they are wet or dry. Data developed by the NIST indicate that firefighters may receive serious burn injuries from thermal exposures that are much less severe than those experienced in either the Flame Resistance or the TPP test used to certify NFPA 1971 protective clothing.

This article has been prepared to present issues that are the basis of current protective clothing research. We have provided this information for firefighters so that they can better understand the thermal performance and limitations of their protective clothing. It is hoped that the information presented will be applied to developing appropriate training and fireground techniques for protecting firefighters from receiving serious burn injuries. ■

Endnotes

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For more information on fire research at the National Institute of Standards and Technology (NIST), connect to the following website:

http://fire.nist.gov